



Seismic Vulnerability of Bijapur's Historic Architecture

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Abstract

Bijapur (Karnataka, India) in recent times, has been experiencing earthquake tremors frequently. The city and its environs are home to numerous historic buildings which are considered significant in the history of architectural development in the Indian subcontinent. The primary and most visual contribution to the city's architecture happened in the 16th – 17th century CE under the Adil Shahi Sultanate. This present study focuses on the buildings of that period only. The buildings are more than 300 years old now and have decayed substantially with time. Recent earthquakes in Bijapur pose a serious threat to these structures and this study tries to assess the seismic vulnerability of the same. From the assessment, it is inferred that the sturdy design of arcuated buildings of Bijapur, arch-frame masonry structures without infill walls, slender building elements like tall minarets, and cantilevered elements like cornices collectively make the historic buildings of Bijapur vulnerable to seismic loads. Lack of maintenance, lack of conservation and consolidation initiatives, vandalism, and unplanned development in close vicinity of these edifices also contribute to the same. The method of assessment employed in this study is based on site surveys, physical documentation, condition assessment, and conceptual and non-conceptual literature available on the subject, instead of computation-based techniques of assessment for those methods have their limitation as far as (historic) masonry buildings are concerned.

Keywords: Seismic Vulnerability, Historic Architecture of Bijapur, Structural and Architectural Analysis.

1. Introduction to Bijapur and its Historic Architecture

Bijapur (now Vijayapura) is located on the northern fringes of the Deccan plateau of peninsular India and is geologically basaltic in nature. The Deccan traps, igneous, have facilitated extensive construction activity in the region for more than a millennium, the 16th – 17th century being the most contributory age. Bijapur stayed under multiple regimes from Chalukyas to British and served as the capital of Adil Shahi Sultanate from 1489 CE - 1686 CE. In this period, numerous architectural establishments embellished the city and the same are its landmarks today. This study is scoped to the Adil Shahi architecture of Bijapur, with occasional reference to pre-Adil Shahi and post-Adil Shahi edifices, whenever necessary. The Adil Shahi architecture of Bijapur (henceforth architectural style of Bijapur/ historic architecture of Bijapur) is

unique to itself and can be considered as an amalgam of indigenous values (expressed through symbolism) and, Persianate technology and overall aesthetics (specifically Iranian). Influences from the then contemporary kingdoms of Vijayanagara, Nizam Shahi, Qutb Shahi, and Mughals were also incorporated equally. The construction is predominantly in compact basalt stone and kiln-burnt clay bricks with lime-based mortar and plaster. Building typologies of Adil Shahi Bijapur include palaces, pavilions, defense structures like fortification walls and gateways, mosques, tombs, and waterbodies. The construction system is arcuated and character-defining features of the Bijapur style of Architecture are three-point arches, flowering domes, slender minarets, petalled parapets, and overhanging cornices supported by

serial brackets. The buildings are mostly plastered on the interior and exterior with lime-based plaster. In the last three centuries, the city witnessed numerous political turbulences and the consequences of that are distinctly visible in its architecture. A large number of palatial structures, fortifications, city gates, wooden buildings, etc. got severely damaged and destroyed in wars and post-war vandalism. Unplanned development after independence has also contributed to this and currently, the threat of earthquake(s) looms over the city.

2. Recent Earthquakes in Bijapur

In the recent past (year 2021 and in 2022), Bijapur (region- a range of 25 kms) witnessed more than 10 minor tremors and more than 05 earthquakes of magnitude higher than 2.0 on richter scale. Below mentioned is the record of few-

YYYY-MM-DD HH:MM: SS (Depth Below Ground Surface) Magnitude on Richter Scale
2022-08-26 14:34:14 (11kms) 2.6, 2022-08-26 06:59:57 (05kms) 3.8, 2022-08-26 02:21:50 (10kms) 3.9, 2022-08-25 00:05:22 (05kms) 3.4, 2022-08-22 16:26:14 (10kms) 2.9, 2022-08-21 18:26:52 (05kms) 3.3, 2022-08-20 20:16:47 (05kms) 3.6

From preliminary studies and concerns expressed by geoscientists and seismologists, it is understood that the movement of tectonic plates and, the presence of a lineament in the vicinity (that might turn/ is turning into a fault line) are causing this seismic activity. No concrete proof for the same has yet been put forth either by concerned government agencies or by anybody from the academic and research fraternity.

Bijapur's historic architecture suffered minor damage during the 1993 Latur earthquake (6.3 magnitude on the Richter scale; 230 kilometers from Bijapur), recorded through crack-embedded glass tubes in Gol Gumbaz (See Figure 1). Also, in 1653-54 CE, Bijapur experienced tremors (the intensity of which is unknown, but it would have been non-disastrous as nothing is mentioned in any source/scripture in that regard [1] [2].

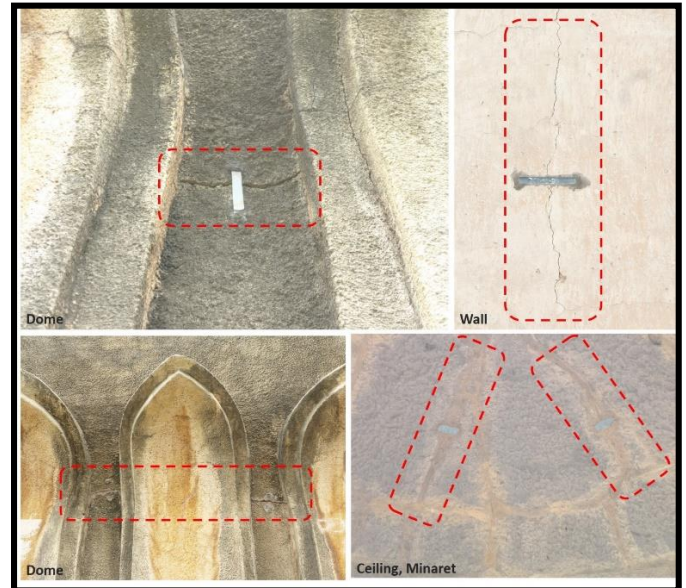


Figure 1 Recorded Damage due to 1993 Latur Earthquake, Gol Gumbaz, Bijapur

3. Reasons for Seismic Vulnerability of Bijapur's Historic Architecture

This present study is based on visual observations, physical surveys of historic buildings, and literature on the subject. Other methods of analyzing the seismic vulnerability of old structures include the analytical cubic polynomial method, quantitative estimation of the damage level of the structural system, Equivalent static analysis, Response spectrum analysis, Linear dynamic analysis, Nonlinear static analysis, Nonlinear dynamic analysis, etc. [3]. In Bijapur's context, with all the above-mentioned methods, the limitation is that- for these methods of assessment to be fruitful, (building) material strength needs to be accurately input, which is tough in the case of historic buildings constructed 300+ years ago, because of following reasons:

3.1 Lab Test and its Limitations

The lab test of these building materials (like lime, stone, brick, etc.) require destructive testing which is not ideal in case of monuments of historic, cultural, and national significance. Even if it is conducted using small samples, it can only be partially accurate in the case of stone and brick as these material samples are in pieces and loose

integrity as it breaks down as a piece of the whole member. And, pulling out a solid un-disturbed, non-broken (stone/ brick) member is tough, given its size and limitations put forth by conservation ethics. In case of lime mortar (and plaster) the test is not able to exactly identify the original ingredients and their composition, which generally has numerous organic additives like turmeric, egg white, eggshell, jute fibers, etc. The reason is that in the last three centuries and more, the organic additives of lime mortar (and plaster) have reacted with each other, biologically and with the minerals and salts found in stone/ brick in contact, chemically. This means that the original ingredient could have been completely lost/decomposed or tuned into a new ingredient or have attained a new form, which the lab test will identify in its current state. This cannot ensure the data collection of the original building material used but this can certainly give details regarding the compressive, tensile or shear strength and stress resilience of the mortar (and plaster). Again, the test has to be conducted with multiple samples collected rationally from multiple parts of the building and multiple buildings in the city, to conclude. A wall, for instance, consists of stone/ brick and lime mortar (and plaster). And, accurate results/ conclusions from lab tests of only one of these materials (say lime mortar) will not provide satisfactory (and real) conclusions regarding present-day capacities of the complete wall, as there are some assumptions dictating the other material's current properties/capacities.

3.2 Referring the IS Codes for Data

The strength of material like stone can be referred from Indian Standard Codes but it is not reliable for the basalt of Bijapur for three reasons. One, the buildings are constructed before the formulation of IS Codes. Two, construction methods and material knowledge of 16th – 17th century CE when (Bijapurs' historic buildings were constructed) varied drastically from that of 19th – 20th century CE (when IS codes were published). Three, though compact in grain, the basalt is subject to severe loss of strength due to defects like weathering, scaling, and coving caused since its first usage. The stones,

used in buildings, are under continuous compression, and in some cases tension also, which in turn affects its strength and cannot be accurately measured. In-situ testing methods have not yet been developed to an extent where correct data can be achieved. And, destructive testing is not ideal, in the case of historically significant monuments.

4. Reasons for the seismic vulnerability of Historic Buildings in Bijapur are of two types- (A) Technical and (B) Administrative and Social

4.1 Technical Reasons

4.1.1 Arcuated System - A Structurally Sturdy Design

With the coming of Tughlaqs to Deccan in the fourteenth century CE, a (then) new construction technology started dictating the architectural vocabulary of the region- the arcuated system. Arcuated system utilizes arches and their successor forms (like vaults and domes) as structural members. On the contrary, the historic architecture of this region since Early Chalukyas employed the trabeated system of construction which comprises post and lintel as primary structural members. Arcuated system, practiced in Deccan and particularly in Bijapur, generally follows an assembly of arches/ arched walls of a square or octagonal enclosure, supporting a hemispherical dome, sitting on a cylindrical drum, with the help of multiple diamond shaped squinches formed by interlacing of arches. Here, the arches/ arched walls are vertical members, the dome is the horizontal roofing member and the squinches act as a load transferring member between the two. The arcuated system has its advantages like long spans can be covered through arches and bigger column-free spaces can be covered under domes. This spanning and overall success of the arcuated system is attributed to the lime mortar that enables basalt stones of varied sizes to bind together, strongly, and sustain for centuries. The masonry (be it for arched walls, arches, squinches, or domes), is robust and turns the edifice into a sturdy mass of stone and lime. The mortar is structurally strong and has lived up to its purpose for more than three centuries now.

The buildings built using arcuated system and the above-mentioned material have been withstanding compressive as well as minor lateral loads. But the only issue that could cause structural damage due to the sturdiness of the historic buildings of Bijapur is their inability to absorb lateral loads generated due to seismic activity.

The seismic loads are resisted in two ways viz. safely absorbing the load (energy dissipation) and base isolation (energy reduction). In case of historic buildings of Bijapur, only absorption of the load can be done and sturdiness is a hurdle to that. The buildings with doubly plastered walls, bulky (mortar filled) roof to wall joints and hollow domical mass set affirm on the top tend to add brittleness to its overall built form, which is reluctant to absorb (dynamic) lateral loads and let the energy of shock wave pass through, leading in diagonal or vertical cracks. It is noteworthy that very few buildings of historically significant stature are possessing sturdiness of this manner, for example Jod Gumbaz, Hyder Khan's Tomb, and Upari Burj, Khwaja Aamin Dargah, Farukh Mahal, to name a few. Whereas a lot of the city's historic architecture is in a state of decay. The Latur earthquake of 1993 caused diagonal cracks on vaulted ceilings of minars and vertical surficial cracks on walls of Gol Gumbaz. A primary reason for this can be attributed to its sturdiness. Contrary to the arcuated system, the trabeated system has historically proved to be a more reliable structural design as far as seismic load absorption/ resilience is concerned. The dry masonry structures, like the temples of Kakatiyas in Telangana and Solanki Temples of Gujrat are examples of that. But dry stone masonry has its limitations, especially spanning large spaces, and arcuated system is an appropriate response to it.

4.1.2 Arch Frame Structures without Masonry Infill

Many structures in Bijapur, mostly mausoleums and waterfront pavilions are built as kiosks with mere four arches forming a square/ rectangular frame supporting a dome/ vaulted roof. Examples of this are sluice gates on Kumatgi Lake, the Bazar

of Ibrahim's old Jami Masjid, an unidentified tomb near Chabuk Savaar Tomb, etc. Such buildings are most vulnerable to seismic loads as there is the availability of a frame (major grid, though no minor grid on wall plane is present) but there is no infill wall within this grid that could absorb the shock(s). The lack of an infill wall makes the arch more vulnerable to distortion in form or collapse when exposed to lateral load in the direction parallel to the arch's spanning plane [4].



Figure 2 Arched Wall with Masonry Infill, Jami Masjid, Bijapur

Studies suggest a masonry arch fails under seismic loads given the depth is less than enough to not turn it into a vault [5]. In case of Bijapur historic architecture, few examples like the pavilion hall of Taj Bawdi, Anand Mahal, Farukh Mahal, etc. have vaulted spaces and will tend to resist the lateral loads better than free-standing arches (e.g., Badi Kaman) or arches without masonry infill. Vernacular buildings of Kashmir, for instance, an area prone to earthquakes, resist the seismic energy using a grid frame and infill system. In this system, the wooden grid of vertical, horizontal, and diagonal

members is erected and then brick and lime/ mud/ cement mortar masonry wall is infilled within the frames. The frame resists the structure from shaking, and infill walls absorb the energy caused by the shaking, resulting in causing less/ no damage to the structure. In case of a few historic buildings in Bijapur that are arch-framed structures without any masonry infill, during an earthquake, performance of these buildings might not be as effective as the vernacular edifices of Kashmir. Jami Masjid of Bijapur has a grid, see Figure 2. The vertical piers of the arch and horizontal masonry wall above arch forms a frame within which the primary structural element, arch, is embedded. A series of such frames stitched to each other through horizontal masonry courses form the long north, south, and west walls. These two-level high long walls can resist lateral loads because of its grid frame structure. Though, it is not clear that the buildings in Adil Shahi Bijapur were designed to resist seismic loads or not. Other factors like building height can also affect the performance of such arch-framed structures that are without any masonry infill, as discussed further in A.5 [6].

4.1.3 Slender Vertical Elements

The built configuration of building elements also determines the vulnerability of the edifice when exposed to seismic loads. It is a character-defining element of the historic architecture of Bijapur that intricacy is exhibited through its fine elements as well as surface decoration. This intricacy and delicate aesthetic are achieved by the provision of numerous tall and slender elements propping out of the structure in the (vertical) y-axis and dominating the buildings' skylines. The elements are minars, minarets, parapet walls, and dome finials. Figure 3 and Figure 4 show a silhouette of the northern façade of Ibrahim Rauza and the dominance of thin free-standing minarets cropping out tall from the building's top-edge-line. The slenderness of such building elements is most vulnerable to seismic loads because the minarets, for example, rise from the top of the roof slab and have very less area as a point of contact with its base (given the aesthetic restriction of not providing a robust masonry base at roof level). So, the anchoring to the base is weak and can cause collapse, in case severe lateral loads are acting on the elements such as seismic load. The same is the case with decorative parapets and miniature minarets/ turrets.

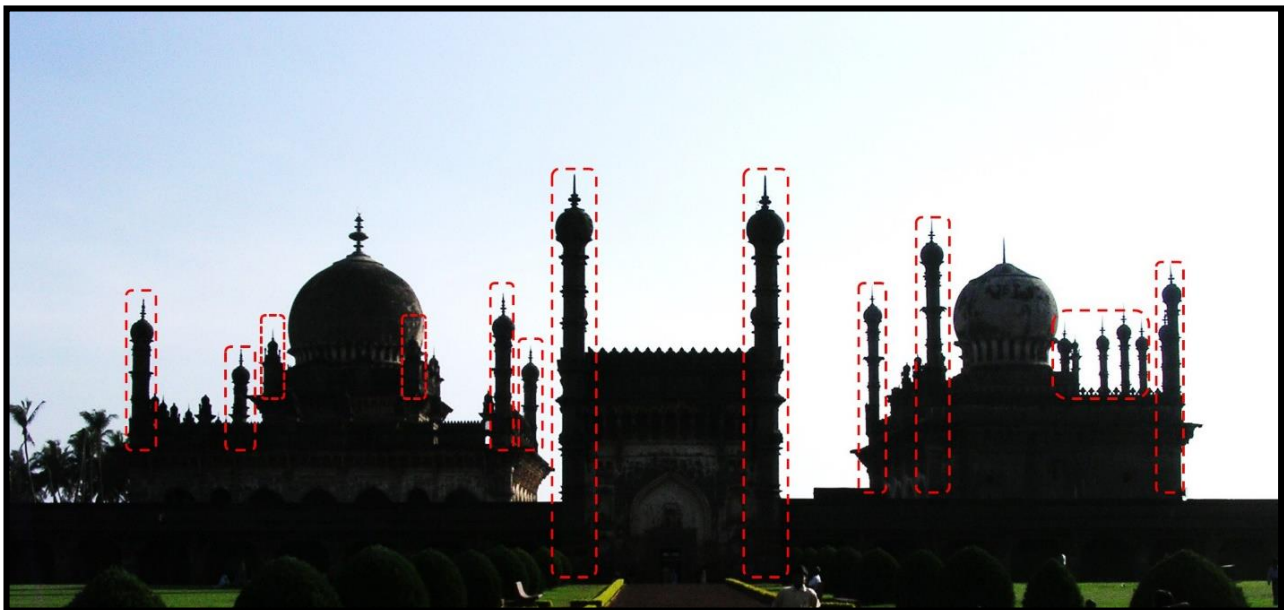


Figure 3 Ibrahim Rauza, Bijapur

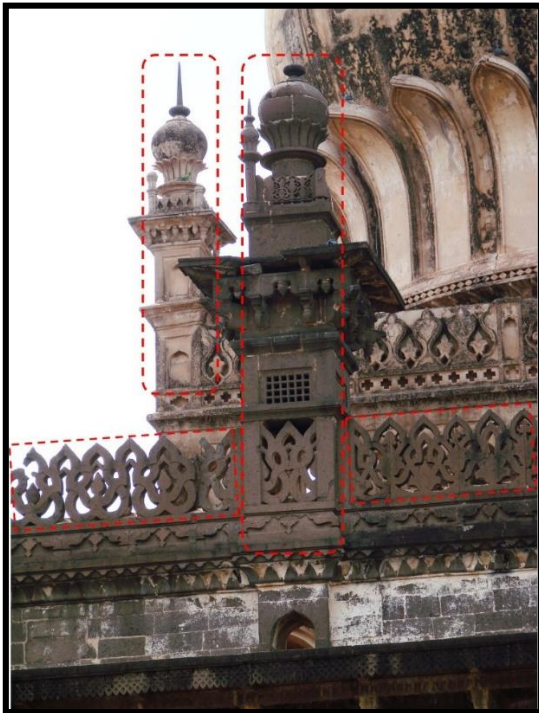


Figure 4 Ibrahim Rauza, Bijapur

4.1.4 Overhangs (Cantilever)

Like slender vertical elements, elegant lotus bud domes, and parapet wall, the most aesthetically pleasing and visually dominating element of historic architecture of Bijapur is the overhanging cornice (chajja) at roof level supported by a series of decorated brackets, all in basalt stone. These overhangs vary from a half meter projection in small structures to more than 04 meters' projection in larger ones. The construction system is simple- a cornice made up of multiple similarly carved stones is embedded in the wall, supported from the bottom by brackets (bracketing) and from the top by a masonry/ parapet wall (counterweight). The brackets are also embedded into the wall. Such assemblies are highly vulnerable to seismic activity because of its cantilevered nature. The brackets and cornice, both in stone, have dead weight that might not pull it down during shaking as the structural assembly maintains equilibrium and the mortar is strong enough to hold it together. But, the stone members, weathered and cracked will fall apart/ break down in a disaster for the integrity of it lost over years, as evident from Figure 5. Examples of weakened and most vulnerable to bumping/

shaking effects of seismic loads are the massive cornices of Mausoleum, Mosque, and Naqqar Khana in Gol Gumbaz-complex.

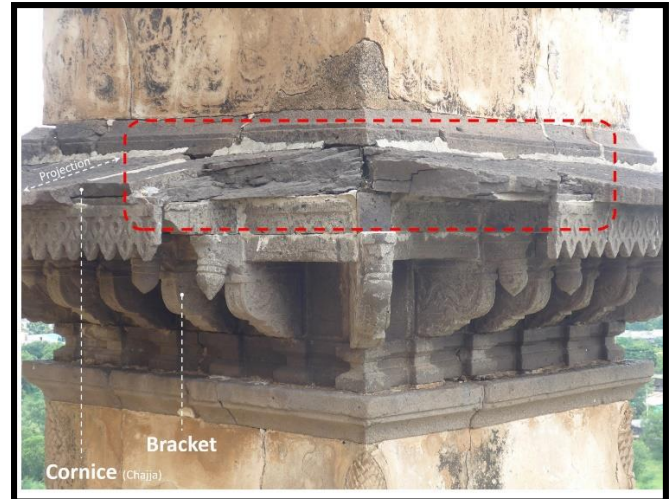


Figure 5 Condition of Stone, Cantilevered Cornice, Northern Turret, Gol Gumbaz, Bijapur (2022)

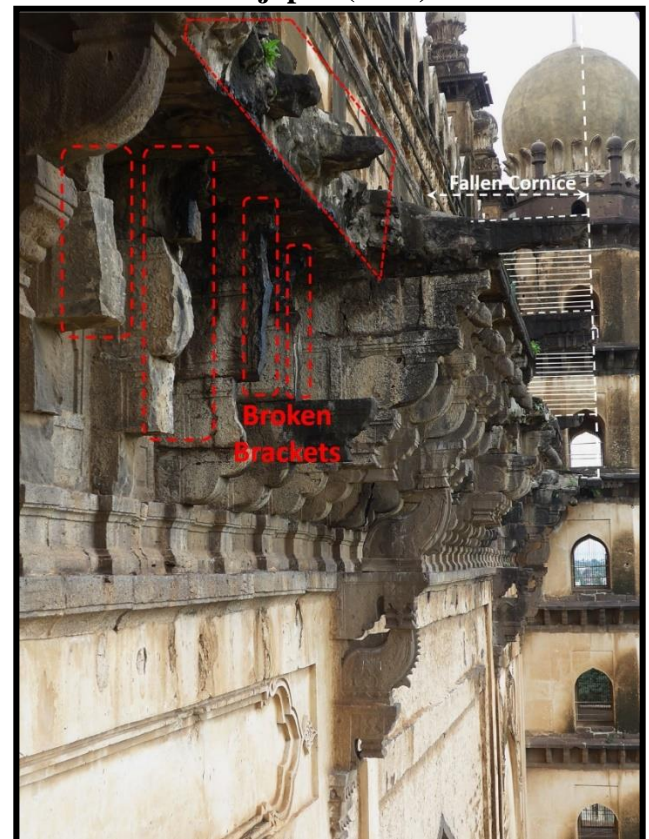


Figure 6 Eastern Cornice, Gol Gumbaz, Bijapur (2022)

The primary reason behind the cornice-bracket system being most affected by weathering and other factors is the poor ability of the compact basalt stone of Bijapur to resist tension forces. Being an igneous rock of Earth's crust surface, its internal fabric (grain) is short length which allows it to take compressive loads effectively, that too with small stone sizes (roughly 1.5m continuous length), but not tensile loads. Therefore, a stone that is poor in tension, already weathering/ decaying rapidly, and subjected to a cantilever structural assembly, altogether makes the cornice and bracket system highly vulnerable to seismic activity from Figure 6.

4.1.5 Building Heights and Shockwave Frequency

As discussed in A.1., an arcuated system (built using lime-based mortar as a binding material is responsible for making the structure sturdy) works differently depending upon its geometric configuration, i.e., overall height and ratio of length and breadth to height. Every masonry structure has a natural resonance frequency, upto which it can take shock wave loads. In a small building, say upto 05-meter high, the diagonally interlaced arches forming a squinch system, might not be able to absorb seismic energy as the travel distance from the foundation to the dome is less. Whereas, the same interlaced squinch system can help the edifice absorb and successfully dissipate the same amount of energy if it is 50 meters high. The shock wave frequency should not synchronize with the natural resonance frequency of a masonry structure, as that can increase the movement and cause damage. It is noteworthy here that the natural resonance frequency of any building is inversely proportional to its height. But that data doesn't help in assessing the vulnerability of historic buildings in any way. It can be of help to analyse the pattern of damage post-disaster [7] [8].

4.2 Administrative and Social Reasons

Generally, masonry structures are assessed for seismic vulnerability on five parameters for viz. a. structural and physical integrity, b. the severity of decay/ damage, c. stiffness, and d. lateral strength, e. geometry (size, shape, and form). This approach

of assessment works efficiently when the study is (one/limited numbers) building-centric. For this present study, structural integrity is a vital parameter as numerous historic buildings of Bijapur have suffered severe damage in the last three centuries. Also, the present state of the structures and their maintenance and consolidation initiatives decide the amount of stress an old building can bear during an earthquake.

4.2.1 Vandalism

Bijapur has experienced vandalism of several kinds since its fall as the Adil Shahi capital with the advent of the Mughals in 1686 CE. The last years of the rulership witnessed several sieges and direct firearm attacks on Bijapur's fortification, which damaged it, and scars of the same are visible to date. Post Mughal, the Maratha occupation proved catastrophic for Bijapur's palatial structures as extensive woodwork was snatched off the courtly edifices and pleasure resorts of the 16th and 17th century CE. Many times, this woodwork happened to be the structural members of the building and its removal weakened the structure. Gagan Mahal, is the most visual example of this. When the city remained under the chaotic rule of the British East India Company, and later under the administration of the British Crown, poverty, and famines led the residents to steal away a lot of stones, bricks (for buildings), and wood (as firewood) from the historic buildings for their domestic use. A trend that trickled down till the 21st century also.

Post-Independence, especially in the last three decades, extensive civic development works in the city, like the laying of underground water supply lines, electrification, drainage, and sewerage networks, and other civic services along with road widening led to a partly planned- partly unplanned urban sprawl. This development has caused irreversible harm to the historic buildings and the city's overall urban fabric, be it in terms of encroachment or demolition. Construction of RCC buildings with deep footings adjacent to historic buildings, construction of permanent buildings abutting fort/ city walls, etc. have weakened the three centuries old masonry buildings structurally,

making them more prone to damage/ collapse during a natural hazard like an earthquake.

5. Strengths of Bijapur's Historic Architecture (Resilience to Seismic Activity)

On a positive note, the arcuated squinch system (making the building sturdy) is an interlocked (in 08 directions) frame that transfers the load, and is good at resisting lateral loads, as internal bracing. A few examples in Bijapur are Gol Gumbaz, the Central Chamber of Jami Masjid, and Shahnawaz Khan's Tomb, among many. The frame will not distort due to its interlocking arrangement made for squinching. But, it is noteworthy here that, during earthquakes, the structure behaves as a whole and not in parts like a frame, walls, dome, etc. So, just the interlocked arch frames also can succumb to damage for it is a part of the sturdy (lime and stone) structure. The bulbous coupla (miniature dome) capping slender tall minars and minarets act as an inverted pendulum and might help in de-synchronizing with the frequency of shaking, attributed to its self-inertia. This means that slenderness with a solid mass on top can save the minar/ minaret from swinging. But there is no technical proof or mathematical explanation to prove this, yet. United Nations Educational Social Cultural Organisation (UNESCO) published guidelines for earthquake-resistant non-engineered construction in 2014 which can also be referred to post assessment of historic buildings in Bijapur [9].

Conclusion

Historic architecture of the 16th - 17th century CE Bijapur is structurally resilient to seismic activity and most of the edifices will not suffer severe damage/ collapse, given the (interlocked arch) squinch system is capable of resisting lateral loads. But, a few aspects of this architectural style like the sturdiness of the lime mortar-based masonry structures, the slenderness of the aesthetic elements like minarets, and the projection of cornices are most vulnerable to damage/ collapse. Weathering for three centuries, lack of maintenance and conservation initiatives, and vandalism have weakened the buildings and have made them prone to seismic activity.

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